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Effects of increasing levels of pea hulls in the diet on productive performance, development of the gastrointestinal tract, and nutrient retention of broilers from one to eighteen days of age

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ABSTRACT

The effects of inclusion of pea hulls (PH) in the diet on growth performance, development of the gastrointestinal tract and nutrient retention were studied in broilers from 1 to 18 d of age. There were a control diet based on low fibre ingredients (69.3 total dietary fibre (16.1 g crude fibre/kg)) and three additional diets that resulted from the dilution of the basal diet with 25, 50 and 75 g PH/kg (81.2, 93.2, and 105.1 g total dietary fibre/kg diet, respectively). Each treatment was replicated six times and the experimental unit was a cage with 12 chicks. Growth performance, development of the gastrointestinal tract and the coefficients of total tract apparent retention (CTTAR) of nutrients were recorded at 6, 12 and 18 d of age. In addition, jejunal morphology was measured at 12 and 18 d and the coefficients of apparent ileal digestibility (CAID) of nutrients at 18 d of age. Pea hulls inclusion affected all the parameters studied. The inclusion of 25 and 50 g PH/kg diet improved growth performance as compared to the control diet. The relative weight (g/kg body weight) of proventriculus ($P \leq 0.01$), gizzard ($P \leq 0.001$) and ceca ($P \leq 0.05$) increased linearly as the level of PH in the diet increased. The inclusion of PH affected quadratically ($P \leq 0.01$) villus height:crypt depth ratio with the highest value shown at 25 g PH/kg. In general, the CTTAR and CAID of nutrients increased linearly and quadratically ($P \leq 0.05$) with increasing levels of PH, showing maximum values with PH level between 25 and 50 g/kg diet. We conclude that the size of the digestive organs increases with increasing levels of PH in the diet. In general, the best performance and nutrient digestibility values were observed with levels of PH within the range of 25 and 50 g/kg. Therefore, young broilers have a requirement for a minimum amount of dietary fibre. When pea hulls are used as a source of fibre, the level of total dietary fibre required for optimal performance is within the range of 81.2–93.2 g/kg diet (25.6–35.0 g crude fibre/kg diet). An excess of total dietary fibre (above 93.2 g/kg diet) might reduce nutrient digestibility and growth performance to values similar to those observed with the control diet.

Abbreviations: ADFI, average daily feed intake; AME_n, apparent metabolisable energy nitrogen corrected; BW, body weight; BWG, body weight gain; CAID, coefficient apparent ileal digestibility; CTTAR, coefficient of total tract apparent retention; DF, dietary fibre; GIT, gastrointestinal tract; PH, pea hulls.

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1. Introduction

The inclusion of moderate amounts of fibre in the diet improved growth performance in chicks fed low-fibre diets (Jiménez-Moreno et al., 2009b; González-Alvarado et al., 2010), an effect that may result from an improvement in gizzard function (González-Alvarado et al., 2008). A well-developed gizzard increases intestinal refluxes and facilitates the mixing of the digesta with HCl and enzymes. Consequently, the inclusion of dietary fibre may improve the digestibility of protein and other dietary components (Svihus and Hetland, 2001; Jiménez-Moreno et al., 2009c) as well as the solubility of the mineral fraction of the diet (Guinotte et al., 1995). However, an excess of dietary fibre reduced feed intake and might hinder nutrient digestibility and growth performance (Jørgensen et al., 1996b; Sklan et al., 2003).

The effects of dietary fibre on gastrointestinal tract (GIT) development, nutrient digestibility and growth performance depends on the level of inclusion and the physicochemical characteristics of the fibre source (Guillon and Champ, 2000; Schneeman, 2001; Mateos et al., 2002; Amerah et al., 2009). Water holding capacity, viscosity, bulk, particle size, fermentability and the ability to bind bile acids of the fibre fraction of the diet have nutritional implications on feed intake, organ development and nutrient digestibility (Bach Knudsen, 2001; Montagne et al., 2003). The mechanisms by which dietary fibre increase viscosity of the digesta or physically trap components of the diet depends largely on the physical properties of the fibre rather than on its chemical composition (Tosh and Yada, 2010). However, the susceptibility to fermentation of the dietary fibre in the ceca, depends primarily on the chemical structure of the fibre source (Morris, 2001).

Peas (*Pisum sativum* L.) are an alternative to soybean meal and cereals in non-ruminant diets (Valencia et al., 2008; Parera et al., 2010). Pea hulls (PH) represent between 90 and 140 g/kg of the mature seed and consist mainly of insoluble non-starch polysaccharides such as cellulose, together with some amounts of pectins and xylans, and small amounts of lignin (Daveby et al., 1993; Castell et al., 1996). Commercial PH contains also a variable proportion of starch and protein that cannot be removed entirely during the air-classification process that separates the different fractions of the peas (Czukor et al., 2001; Valencia et al., 2009). We hypothesized that the inclusion of a moderate amount of PH to diets low in fibre, may improve the development of the GIT of young broilers, increasing nutrient digestibility and growth performance but that high levels of PH may have detrimental effects on some of these traits. The objective of this experiment was to study the effects of increasing levels of PH in the diet on digestive traits, nutrient digestibility and productive performance in broilers from 1 to 18 d of age.

2. Materials and methods

2.1. Pea hulls and diets

A batch of PH was obtained from a supplier of pea protein concentrate destined to the animal feed industry (Esasa, Valladolid, Spain). The batch was ground through a rotor mill (Retsch GmbH Model ZM 200, Haan, Germany) fitted with a 2.0-mm screen, and used as such in the manufacturing of the feeds. The chemical composition of the PH used is shown in Table 1. The basal diet was formulated using low-fibre ingredients and contained 13.7 MJ apparent metabolisable energy nitrogen corrected (AME_n)/kg and 69.3 g total dietary fibre (DF)/kg (FEDNA, 2003). Celite, an acid-washed diatomaceous earth (Celite Hispánica S.A., Alicante, Spain) was added (20 g/kg) to the basal diet as an acid insoluble ash source. The remaining diets had similar ingredient composition to the basal diet but 25, 50 or 75 g PH/kg substituted (weight/weight) identical amounts of the basal diet. All diets met or exceeded the nutritional recommendations of FEDNA (2008) for broilers (Table 2).

2.2. Husbandry and experimental design

All procedures used in this research were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2005).

In total, 288 1 d-old female broiler (Ross-308) chicks with an initial body weight (BW) of 43.0 ± 3.1 g were obtained from a commercial hatchery (Avimosa, Moraleja de Enmedio, Spain), allocated in a windowless, environmentally controlled room and randomly placed in groups of 12 in 24 battery cages (1 m × 0.9 m; Avícola Grau, Madrid, Spain). Chicks were divided into six blocks by BW and diets were randomly assigned to cages within each block. The cages had complete wire flooring and were equipped with two drinker cups and an open trough feeder. Room temperature was kept at 33 °C during the first 3 d of life and then, was reduced gradually according to age until reaching 24 °C at 18 d. Chicks received a 23 h/d light program and had free access to feed in mash form and tap water throughout the trial.

2.3. Laboratory analysis

Pea hulls, diets, excreta and ileal digesta were analysed for total ash using the muffle furnace (method 942.05) and for nitrogen by Dumas (method 968.06) using a LECO analyser (model FP-528, Leco Corporation, St. Joseph, MI) as described by AOAC International (2000). Dry matter was determined by oven-drying (method 6) and ether extract by Soxhlet fat analysis after 3N HCl acid hydrolysis (method 4.b) as described by Boletín Oficial del Estado (1995). Gross energy was measured with an isoperibol bomb calorimeter (model 356, Parr Instrument Company, Moline, IL) and acid insoluble ash was analysed as

Table 1
Determined chemical composition (g/kg, as-fed basis), geometric mean diameter (μm), water holding capacity (L/kg dry matter) and lipid adsorption capacity (g oil/g dry matter) of pea hulls[a].

	Pea hulls
Chemical analysis	
Gross energy (MJ/kg)	16.23
Dry matter	903
Crude protein	121
Starch	89
Ether extract	13.5
Total ash	39.6
Crude fibre	393
Total dietary fibre	547
Insoluble dietary fibre	496
Soluble dietary fibre	51
Neutral detergent fibre[b]	470
Acid detergent fibre[b]	358
Acid detergent lignin	10.5
Physical properties	
Screen size (μm)	
1250	214
630	543
315	155
160	67
80	17
<40	4
Geometric mean diameter	805
Geometric standard deviation[c]	1.87
Water holding capacity	5.54
Standard deviation	0.031
Lipid adsorption capacity	2.13
Standard deviation	0.066

[a] Analysed in triplicate samples.
[b] Neutral detergent and acid detergent fibre were determined exclusive of ash.
[c] Log normal geometric standard deviation.

Table 2
Ingredient composition and calculated nutritive value (g/kg, as-fed basis, unless otherwise indicated) of the experimental diets.

	Pea hulls (g/kg)			
	0	25	50	75
Ingredient				
Cooked rice	577.5	563.1	548.6	534.2
Soy protein concentrate (530 g CP[a]/kg)	240.0	234.0	228.0	222.0
Fish meal (720 g CP/kg)	76.0	74.1	72.2	70.3
Soy oil	50.0	48.7	47.5	46.2
Pea hulls	–	25.0	50.0	75.0
Limestone	11.50	11.21	10.93	10.64
Dicalcium phosphate	15.00	14.65	14.26	13.88
Sodium chloride	3.00	2.92	2.85	2.79
DL-Methionine (990 g/kg)	2.00	1.95	1.90	1.85
Celite[b]	20.00	19.50	19.00	18.50
Vitamin and mineral premix[c]	5.00	4.87	4.76	4.64
Calculated analysis[d]				
AME_n (MJ/kg)	13.67	13.45	13.23	13.01
Crude fibre	16.1	25.6	35.0	44.4
Digestible lysine	12.5	12.2	12.0	11.8
Digestible methionine	5.8	5.6	5.5	5.3
Digestible methionine + cystine	9.0	8.8	8.7	8.5
Digestible threonine	8.1	7.9	7.7	7.6
Calcium	10.7	10.4	10.2	10.0
Available phosphorus	41.0	41.0	40.0	39.0

[a] Crude protein.
[b] Acid-washed diatomaceous earth (Celite Hispánica, S.A., Alicante, Spain).
[c] Provided the following (per kg of diet): vitamin A (transretinyl acetate), 10,000 IU; vitamin D_3, (cholecalciferol), 2000 IU; vitamin E (all-*rac*-tocopherol acetate), 20 IU; vitamin K (bisulphate menadione complex), 3 mg; riboflavin, 5 mg; pantothenic acid (D-calcium pantothenate), 10 mg; nicotinic acid, 30 mg; pyridoxine (pyridoxine·HCl), 3 mg; thiamin (thiamin-mononitrate), 1 mg; vitamin B_{12} (cyanocobalamine), 12 μg; D-biotin, 0.15 mg; choline (choline chloride), 300 mg; folic acid, 0.5 mg; Se (Na_2SeO_3), 0.1 mg; I (KI), 2.0 mg; Cu ($CuSO_4 \cdot 5H_2O$), 10 mg; Fe ($FeSO_4 \cdot 7H_2O$), 30 mg; Zn (ZnO), 100 mg; Mn ($MnSO_4 \cdot H_2O$), 100 mg; and ethoxyquin, 110 mg.
[d] According to FEDNA (2003).

indicated by González-Alvarado et al. (2007). Total DF and the insoluble fraction of the DF of the fibre sources and diets were determined by an enzymatic-gravimetric method using the Total Dietary Fibre kit of Megazyme International Ireland Ltd. (Bray, Co. Wicklow, Ireland). Soluble DF was calculated by difference between total and insoluble DF. Crude fibre of PH was measured by sequential extraction with diluted acid and alkali (method 962.09) as indicated by AOAC International (2000). The neutral and acid detergent fibre of PH and diets and acid detergent lignin of PH were determined sequentially as described by van Soest et al. (1991) and expressed on an ash-free basis. Starch content of PH, diets and ileal contents were measured using amyloglucosidase/α-amylase (method 996.11 of the AOAC International, 2000) and particle size distribution and geometric mean diameter of PH and the experimental diets according to the methodology recommended by the ASAE (1995). Water holding capacity of PH and experimental diets and lipid adsorption capacity of the PH were determined as indicated by González-Alvarado et al. (2008) and Jiménez-Moreno et al. (2010), respectively. All the analyses were conducted in triplicate for PH, diets and excreta samples and in duplicate for ileal samples.

2.4. Productive performance, water intake and moisture content of the excreta

Body weight of chicks and feed consumption were determined by cage at 1, 6, 12 and 18 d of age, and BW gain (BWG), average daily feed intake (ADFI) and feed/gain ratio were determined from these data by period and cumulatively. Feed wastage was recorded daily and birds that died during the experiment were weighed, and these data were used in the calculations of feed/gain ratio. In addition, energy efficiency, expressed as MJ of AME_n required per kg of BWG, was estimated by multiplying the ADFI by the AME_n of the diets determined at each of the three experimental periods (6, 12 and 18 d of age) and cumulatively (González-Alvarado et al., 2010). Water intake, expressed as g/bird/d, was measured by cage from 6 to 8 d and from 16 to 18 d of age and water/feed intake ratio was calculated from these data. Also, the moisture content of the excreta was determined at 6, 12 and 18 d of age.

2.5. Development of the GIT, pH of the digestive segments and jejunal morphology

At 6, 12 and 18 d of age, two chicks per cage were randomly selected, weighed individually and euthanised by asphyxiation with CO_2. The digestive tract with contents (from the end of the crop to the cloaca) was removed aseptically and weighed. Then, the proventriculus, gizzard, small intestine (duodenum + jejunum + ileum), ceca, liver and pancreas were excised, cleaned and measured. Prior to digesta emptying, the proventriculus, gizzard and duodenum (from the gizzard to the entry of the bile and pancreatic ducts) were clamped to avoid bolus contamination among segments. Digesta pH was then measured within each segment using a digital pH-meter (Model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jiménez-Moreno et al. (2009a). The pH was recorded twice, and the mean of the two birds per cage was used for statistical evaluation. The digesta of the proventriculus, gizzard and ceca was removed and the empty organs were cleaned, dried with desiccant paper and weighed. The fresh digesta content of these organs were measured also at these ages and expressed relative to the weight of the full organ (g/kg). In addition, the dry matter content of the gizzard digesta was determined at 18 d of age. The weight of the empty organs was expressed relative to live BW (g/kg) and the length of the small intestine and the ceca were determined and expressed relative to empty BW (cm/kg) at the same ages than organ size measurements. Also, villi height and associated crypts depth of samples taken from the middle part of the jejunum were measured in these birds at 12 and 18 d of age as indicated by Chamorro et al. (2007). Briefly, the jejunal samples (6-cm) were dehydrated gradually in an ethanol series (50–100%), embedded in paraffin, sectioned at 6.0-μm and stained with hematoxylin and eosin. Four to six slides containing jejunal cross sections were prepared from each sample and viewed at 40$\times$ magnification using an Olympus BX-40 light microscope. Images were digitally captured for later analysis using the Soft software version 3.2 C4040Z (Soft Imaging System, Olympus, GmbH, Hamburg, Germany). The average of the measurements taken from three independent cross-sectional jejunal samples, with a minimum of ten measurements from each of them, was used for further analysis.

2.6. Coefficients of the total tract apparent retention and apparent ileal digestibility of nutrients

At 6, 12 and 18 d of age, grab samples of excreta (235 ± 25 g) produced during two consecutive days were collected daily by replicate, mixed, homogenized, dried in an oven (60 °C for 72 h) and weighed. Also, five birds per replicate chosen at random were euthanised by asphyxiation with CO_2 at 18 d of age and the ileal digesta was collected by gently flushing the contents with distilled water into plastic containers, pooled, frozen at −20 °C and freeze-dried. The samples of excreta were ground with a rotor mill fitted with a 1.0-mm screen and that of ileal digesta with a mixer mill (Models ZM 200 and MM 400, Retsch GmbH, Hann, Germany, respectively) and stored in airtight containers at room temperature until chemical analyses. The coefficients of total tract apparent retention (CTTAR) of dry matter, organic matter, nitrogen, soluble ash, ether extract and the coefficients of apparent ileal digestibility (CAID) of dry matter, organic matter, nitrogen and starch and the AME_n of the diets were estimated by the indigestible marker method using 2N HCl insoluble ash as an indicator (González-Alvarado et al., 2007). The CTTAR and CAID of the nutrients were calculated according to the following equation:

$$\text{CTTAR or CAID} = 1 - \left[\left(\frac{AIA_{fd}}{AIA_{fc}}\right) \times \left(\frac{N_{fc}}{N_{fd}}\right)\right]$$

where AIA_{fd} and AIA_{fc} represent 2N HCl insoluble ash content in food and excreta or ileal digesta and N_{fc} and N_{fd} are the nutrients in food and excreta or ileal digesta, respectively. The AME_n of the diets was calculated as indicated by Lázaro et al. (2003).

2.7. Statistical analysis

Growth performance data were analysed as a completely randomized block design. Orthogonal polynomial contrasts were performed to study the linear and quadratic effects of dietary PH level and age on the traits studied. Results in tables are reported as least-square means. Differences were considered significant at $P<0.05$ and tendencies at $0.10<P<0.05$. Significant differences between treatment means were separated by the protected *t*-test. Data on moisture content of the excreta, digestive traits and CTTAR of nutrients were analysed by the MIXED procedure of SAS (Littell et al., 1996) and those on dry matter content of the gizzard digesta, jejunal morphology and CAID of nutrients by the GLM procedure of SAS (SAS Institute, 1990). For data on development of the GIT, pH and digesta content of the digestive segments, jejunal morphology, CTTAR of nutrients and AME_n, age was included as a second main factor in the model and the interaction between PH level and age was studied. In addition, the maximum and minimum level of PH in the diet for optimal growth performance, AME_n efficiency, and CTTAR and CAID of nutrients were calculated by regression using the REG procedure of SAS (SAS Institute, 1990). The experimental unit was the cage for all traits.

3. Results

The PH contained 121 g crude protein, 89 g starch and 470 g neutral detergent fibre, 358 g acid detergent fibre, 496 g insoluble DF and 51 g soluble DF/kg and had a geometric mean diameter, water holding capacity and lipid adsorption capacity of 805 μm, 5.54 L/kg dry matter and 2.13 g oil/g dry matter, respectively (Table 1). An increase in the level of PH resulted in a reduction in crude protein and starch, and an increase in neutral and acid detergent fibre, and insoluble and soluble DF content of the diet (Table 3). The inclusion of PH increased the geometric mean diameter of the diet but did not affect water holding capacity (Table 3).

3.1. Productive performance, water intake and moisture content of the excreta

Mortality was low (2.8%) and not related to treatment (data not shown). Most of the mortality (>75%) occurred during the first week of life. From 10 to 12 d of age birds throughout the barn were affected at random by a mild wet litter problem. The

Table 3
Determined chemical composition (g/kg, as-fed basis), geometric mean diameter (μm) and water holding capacity (L/kg of dry matter) of the experimental diets[a].

Item	Peas hulls (g/kg)			
	0	25	50	75
Chemical analysis				
Gross energy (MJ/kg)	17.08	16.86	16.91	17.01
Dry matter	899	903	902	900
Crude protein	221	217	215	212
Starch	415	407	398	390
Ether extract	56.8	55.5	52.6	52.1
Total ash	78.9	80.9	81.0	79.1
Total dietary fibre	69.2	81.2	93.2	105.1
Insoluble dietary fibre	47.7	58.9	70.1	81.3
Soluble dietary fibre	21.6	22.3	23.1	23.8
Neutral detergent fibre[b]	39.8	47.8	59.9	71.4
Acid detergent fibre[b]	19.6	25.2	30.3	37.7
Physical properties				
Screen size (μm)				
1250	65.1	68.3	79.6	96.6
630	190.8	480.8	381.7	376.8
315	464.2	430.8	506.1	490.3
160	270.5	20.1	32.4	36.2
80	9.2	0.2	0.2	0.0
<40	0.2	0.0	0.0	0.0
Geometric mean diameter	458	674	634	646
Geometric standard deviation[c]	1.83	1.57	1.62	1.65
Water holding capacity	2.04	2.10	2.12	2.07
Standard deviation	0.209	0.140	0.231	0.079

[a] Analysed in triplicate samples.
[b] Neutral detergent and acid detergent fibre were determined exclusive of ash.
[c] Log normal geometric standard deviation.

Table 4
Effect of dietary pea hulls (PH) on average daily gain (BWG, g/d), average daily feed intake (ADFI, g), feed/gain ratio and energy efficiency[a] (g body weight gain/MJ apparent metabolisable energy nitrogen corrected ingested) of broilers.

Item	PH (g/kg)				S.E.M.[b]	P-value	
	0	25	50	75		Linear	Quadratic
1–6 d							
BWG	16.7	17.1	18.5	17.4	0.39	0.071	0.076
ADFI	19.2	18.9	20.6	19.8	0.42	0.083	0.545
Feed/gain ratio	1.147^{x}	1.104^{z}	1.114^{yz}	1.136^{xy}	0.0089	0.582	0.002
Energy efficiency	65.0^{y}	67.0^{x}	67.1^{x}	67.2^{x}	0.53	0.014	0.072
6–12 d							
BWG	29.9	31.0	33.3	32.5	1.28	0.103	0.489
ADFI	39.7	40.0	42.8	42.1	1.62	0.186	0.774
Feed/gain ratio	1.325^{x}	1.290^{y}	1.285^{y}	1.293^{y}	0.0090	0.025	0.033
Energy efficiency	56.8^{z}	57.8^{y}	58.8^{xy}	59.6^{x}	0.40	<0.001	0.413
12–18 d							
BWG	41.1^{y}	43.0^{xy}	48.9^{x}	41.0^{y}	1.96	0.543	0.024
ADFI	61.2	61.1	70.1	62.5	2.11	0.188	0.094
Feed/gain ratio	1.497^{xy}	1.420^{y}	1.438^{y}	1.536^{x}	0.0319	0.360	0.015
Energy efficiency	49.9	52.2	51.8	49.5	1.08	0.722	0.052
1–18 d							
BWG	30.0^{y}	31.2^{y}	34.5^{x}	31.1^{y}	1.01	0.167	0.034
ADFI	41.2	41.2	45.9	39.6	1.15	0.255	0.218
Feed/gain ratio	1.376^{x}	1.323^{y}	1.332^{y}	1.378^{x}	0.0139	0.793	0.003
Energy efficiency	54.3^{y}	56.1^{x}	56.2^{x}	55.4^{xy}	0.57	0.207	0.033

[a] g ADG/MJ of apparent metabolisable energy nitrogen corrected (AME_n) ingested. The AME_n values were determined at 6 d of age for the 1–6 d of age period, at 12 d of age for the 6–12 d of age period and at 18 d of age for the 12–18 d of age period. The average of values obtained at 6, 12 and 18 d of age was used to estimate the AME_n of the diets for the entire experimental period.
[b] Standard error of mean (six replicates of 12 birds each per treatment).
x–z Means within a row not sharing a common superscript are different ($P \leq 0.05$).

subclinical symptoms, which resulted in higher excreta moisture content, disappeared with age and no antibiotic treatment was needed.

From 1 to 6 d of age, a quadratic effect ($P \leq 0.01$) of level of PH on feed/gain ratio was observed; the inclusion of 25 g PH/kg improved feed/gain ratio but the inclusion of 75 g/kg had an opposite effect (Table 4). From 6 to 12 d of age, feed/gain ratio improved (linear, $P \leq 0.05$; quadratic, $P \leq 0.05$) with the inclusion of 25 g/kg diet but no further improvements were observed with further increases. From 12 to 18 d of age, an increase in dietary PH of up to 50 g/kg diet improved BWG ($P \leq 0.05$) and feed/gain ratio ($P \leq 0.05$) and tended to improve ADFI ($P=0.09$) but a further increase to 75 g PH/kg diet impaired growth performance. For the entire experimental period, BWG ($P \leq 0.05$) and feed/gain ratio ($P \leq 0.01$) improved as dietary PH increased up to 50 g/kg but both variables were hindered with 75 g PH/kg diet. When growth performance data were analysed by regression, the best BWG and feed/gain ratio were observed at 45.3 and 36.6 g PH/kg diet which corresponded to 90.9 and 86.8 g total DF/kg diet (33.2 and 29.9 g crude fibre/kg diet), respectively (data not shown). Similarly, the best energy efficiency was observed with PH levels between 25 and 50 g/kg diet (Table 4).

From 6 to 8 d of age, water intake tended to increase linearly ($P=0.08$) with increases in dietary PH but no effects were detected from 16 to 18 d of age (Table 5). The water/feed intake ratio and the moisture content of the excreta were not affected by PH inclusion, but moisture content of the excreta was higher at 12 d than at 6 or 18 d of age ($P \leq 0.001$).

3.2. Development of the GIT, pH of the digestive segments and jejunal morphology

3.2.1. Effect of age

Most of the digestive variables studied were affected by age. The relative weight of the liver, pancreas, and full GIT decreased linearly ($P \leq 0.001$) with age (Table 6). In addition, a quadratic effect was observed for the relative weight of the liver ($P \leq 0.05$), full GIT ($P \leq 0.001$), proventriculus ($P \leq 0.001$), gizzard ($P \leq 0.001$) and ceca ($P=0.08$).

The relative weight of the fresh digesta content of the ceca increased linearly ($P \leq 0.001$) and quadratically ($P \leq 0.01$) with age (Table 7). The digesta pH of the proventriculus and gizzard, but not that of the duodenum, was reduced linearly ($P \leq 0.001$) with age (Table 8). Also, the relative length of the small intestine and ceca decreased (linearly, $P \leq 0.001$; quadratic, $P \leq 0.001$) with age (Table 9). Crypt depth was reduced ($P \leq 0.001$) with age but villus height was not affected and consequently, villus height:crypt depth ratio increased ($P \leq 0.05$) with age (Table 10).

3.2.2. Effect of PH inclusion

The relative weight of the full GIT increased (linear, $P \leq 0.001$; quadratic, $P \leq 0.01$) as the level of PH increased from 0 to 75 g/kg diet (Table 6). Also, an increase in dietary PH produced a linear increase in the relative weight of the proventriculus ($P \leq 0.01$), gizzard ($P \leq 0.001$) and ceca ($P \leq 0.05$). The relative weight of the fresh content (linear, $P \leq 0.001$; quadratic, $P \leq 0.001$) and the dry matter content (linear, $P \leq 0.05$; quadratic, $P \leq 0.01$) of the gizzard increased as the level of PH increased (Table 7);

the inclusion of 25 g PH/kg increased both variables but no further increases were observed with further PH increases. Also, the inclusion of 25 g PH/kg diet reduced digesta pH of the proventriculus (P≤0.01) and gizzard (P≤0.001) but no further reductions were observed with further increases in dietary PH (Table 8). The relative length of the small intestine and ceca were not affected by PH inclusion (Table 9).

An increase in dietary PH tended to reduce linearly villus height (P=0.09) and reduced linearly crypt depth (P≤0.05) of the mucosa of the jejunum and the reduction in crypt depth was more pronounced (P=0.05) at 12 d than at 18 d of age (Table 10). Consequently, the inclusion of 25 g PH/kg diet increased the villus height:crypt depth ratio but a further increase to 75 g PH/kg had an opposite effect (P≤0.01).

3.3. CTTAR and CAID of nutrients

3.3.1. Effect of age

No interactions between PH inclusion and age were detected for any of the coefficients of digestibility studied and therefore, only main effects are reported. For all nutrients, except for organic matter that tended to increase linearly (P=0.074) and for nitrogen that was not affected, the lowest (P≤0.05) CTTAR were observed at 12 d of age (Table 11).

3.3.2. Effect of PH inclusion

In general, the CTTAR and CAID of nutrients responded linearly and quadratically to increases in dietary PH (Table 11). The CTTAR and CAID of all nutrients were improved with 25 g PH/kg diet. However, a further increase to 50 g PH/kg reduced CTTAR of dry matter and organic matter. Moreover, the inclusion of 75 g PH/kg diet impaired the digestibility of all nutrients except that of ether extract that was unaffected. When the CTTAR and CAID of nutrients were analysed by regression, the maximal values were observed at inclusion levels ranging from 25 to 50 g PH/kg diet (81.2–93.2 g total DF/kg diet; data not shown).

4. Discussion

4.1. Productive performance, water intake and moisture content of the excreta

From 1 to 18 d of age, an increase in dietary PH from 0 to 50 g/kg improved BWG by 15% and feed/gain ratio by 3%. However, a further increase to 75 g PH/kg hindered both parameters although the values were still similar to those observed in broilers fed the control diet. The optimal PH level estimated by regression analysis was 45.3 g/kg for BWG and 36.6 g/kg for feed/gain ratio, values that corresponded to 90.9 and 86.8 g total DF/kg diet, respectively. Similar response has been reported by Jiménez-Moreno et al. (2007) when 25 and 50 g oat hulls, rice hulls or sunflower hulls/kg were included in low fibre diets for broilers from 1 to 21 d of age. Rogel et al. (1987) reported that the inclusion of 20 g oat hulls/kg in a highly digestible diet, increased ADFI in broilers from 1 to 42 d of age as compared to those fed the control diet but that a further increase to 40 g/kg had a negative effect. Pettersson and Razdan (1993) observed that broilers fed a diet that contained 23 g sugar beet pulp/kg had higher BW, ADFI and better feed/gain ratio from 1 to 21 d of age than broilers fed the control diet. However, when the level of sugar beet pulp was increased to 46 and 92 g/kg, growth performance was impaired. Also, Jørgensen et al. (1996b) reported that broilers fed a control diet containing 45 g total non-starch polysaccharides/kg had lower ADFI, BWG

Table 5
Effect of dietary pea hulls (PH) on water intake, water:feed intake ratio and moisture content of the excreta in broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value[c]			
	0	25	50	75				PH		Age	
								Linear	Quadratic	Linear	Quadratic
Water intake (g/bird/d)											
6–8 d	64.7	67.1	75.0	69.4		2.65		0.086	0.150		
16–18 d	141.5	141.4	156.4	147.8		6.81		0.285	0.545		
Water:feed ratio											
6–8 d	1.89	1.87	1.89	1.82		0.056		0.438	0.705		
16–18 d	2.14	2.21	2.10	2.11		0.075		0.565	0.662		
Excreta moisture (g/kg)											
6 d	570	567	632	590	590[Y]	35.1	17.5				
12 d	636	640	678	611	641[X]	27.1	13.5				
18 d	613	610	627	596	611[Y]	30.5	15.2				
Average[d]	606	606	645	599		26.8		0.891	0.401	0.199	<0.001

[a] Standard error of mean for diet effect ($n=6$ for each individual day and $n=18$ for average age value).
[b] Standard error of mean for age effect ($n=24$ observations for each age).
[c] The interaction between PH level and age for excreta moisture was not significant (P>0.10).
[d] Average of data at 6, 12 and 18 d of age.
[X,Y] Means within a column not sharing a common superscript are different (P≤0.05).

Table 6
Effect of dietary pea hulls (PH) in the diet on the relative weight of digestive organs (g/kg body weight) of broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value[c]			
	0	25	50	75				PH		Age	
								Linear	Quadratic	Linear	Quadratic
Empty BW[d]											
6 d	775	754	752	743	756^{Z}	6.0	3.0				
12 d	828	815	814	808	816^{Y}	4.2	2.1				
18 d	861	850	845	847	851^{X}	3.4	1.7				
Average[e]	821^{x}	806^{y}	804^{y}	799^{y}		2.3		<0.001	0.033	<0.001	<0.001
Full GIT[f]											
6 d	173.1	186.3	191.3	196.9	186.9^{X}	3.29	1.65				
12 d	126.9	136.7	140.8	146.5	137.7^{Y}	2.69	1.35				
18 d	101.3	114.8	114.0	114.0	111.0^{Z}	2.76	1.38				
Average	133.8^{z}	145.9^{y}	148.7^{y}	152.5^{x}		1.39		<0.001	0.008	<0.001	<0.001
Proventriculus											
6 d	9.3	10.0	9.9	10.7	10.0^{X}	0.22	0.11				
12 d	5.7	6.3	6.1	6.3	6.1^{Y}	0.20	0.10				
18 d	4.5	5.3	4.8	5.1	4.9^{Z}	0.17	0.08				
Average	6.5^{y}	7.2^{x}	7.0^{xy}	7.4^{x}		0.14		0.003	0.377	<0.001	<0.001
Gizzard											
6 d	32.7	37.1	39.0	43.6	38.1^{X}	1.25	0.63				
12 d	18.3	21.8	22.5	25.3	25.3^{Y}	0.76	0.38				
18 d	12.3	16.9	18.0	19.5	19.5^{Z}	0.86	0.43				
Average	21.1^{z}	25.3^{y}	26.5^{y}	29.5^{x}		0.54		<0.001	0.301	<0.001	<0.001
Ceca											
6 d	5.5	5.4	5.7	6.8	5.9^{X}	0.33	0.16				
12 d	4.9	5.3	5.0	4.7	5.0^{Y}	0.43	0.22				
18 d	4.5	5.5	5.5	5.2	5.1^{Y}	0.43	0.22				
Average	5.0^{y}	5.4^{xy}	5.4^{xy}	5.6^{x}		0.19		0.048	0.454	0.008	0.081
Liver											
6 d	49.5	48.6	46.9	47.0	48.0^{X}	1.49	0.74				
12 d	36.6	34.8	36.3	34.0	35.4^{Y}	1.33	0.67				
18 d	26.8	26.1	26.0	30.1	27.3^{Z}	1.26	0.63				
Average	37.6	36.5	36.4	37.0		0.77		0.586	0.265	<0.001	0.014
Pancreas											
6 d	4.2	3.8	4.6	4.5	4.3^{X}	0.26	0.13				
12 d	3.5	3.5	3.8	4.0	3.7^{Y}	0.15	0.07				
18 d	3.1	3.3	3.2	3.3	3.2^{Z}	0.12	0.06				
Average	3.6^{xy}	3.5^{y}	3.8^{xy}	3.9^{x}		0.13		0.043	0.610	<0.001	0.658

[a] Standard error of mean for diet effect ($n=6$ for each individual day and $n=18$ for average age value).
[b] Standard error of mean for age effect ($n=24$ observations for each age).
[c] The interactions between PH level and age for relative weight of the digestive organs were not significant (P>0.10).
[d] Empty body weight without the liver, pancreas and the digestive tract with contents.
[e] Average of data at 6, 12 and 18 d of age.
[f] From end of the crop to the cloaca including all digesta content.
[x–z] Means within a row not sharing a common superscript are different ($P \leq 0.05$).
[X–Z] Means within a column not sharing a common superscript are different ($P \leq 0.05$).

and feed/gain ratio than broilers fed a diet containing 251 g/kg. All this information is consistent with our hypothesis that the effects of dietary fibre on broiler performance depend on the source and level of fibre used.

The inclusion of PH in the diet improved energy efficiency at all ages, in agreement with results of González-Alvarado et al. (2010) in broilers from 1 to 42 d of age fed diets containing 30 g oat hulls or sugar beet pulp/kg and suggests that the beneficial effects of dietary fibre on feed/gain ratio and growth performance of broilers were due primarily to an increase in diet digestibility which resulted in more nutrients available for growth.

The water intake and water:feed intake ratio were little affected by PH inclusion, in agreement with data of Jiménez-Moreno et al. (2008) in broilers fed 25 or 50 g oat hulls, rice hulls or sunflower hulls/kg. The moisture content of the excreta was not affected by PH inclusion in disagreement with data of Jørgensen et al. (1996b) who observed an increase in moisture as the level of fibre from peas increased from 0 to 375 g/kg diet. Probably, the higher levels of PH used in their experiment accounts for the discrepancy observed.

4.2. Development of the GIT, pH of the digestive segments and jejunal morphology

The relative weight of the liver and pancreas and of most segments of the GIT, and the relative length of the small intestine and ceca, decreased with age results that agree with data of González-Alvarado et al. (2008) and Gracia et al. (2009). The relative weight of the full GIT, proventriculus, gizzard and ceca increased as the PH level increased, in agreement with data of Jørgensen et al. (1996b) who observed that the relative weight and relative length of the GIT increased as the level of PH

Table 7
Effect of dietary pea hulls (PH) in the diet on the and relative weight (g/kg full segment) of the fresh digesta contents of the different segments of the gastrointestinal tract and gizzard dry matter (DM) content (g/kg full gizzard) of broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value[c]			
	0	25	50	75				PH		Age	
								Linear	Quadratic	Linear	Quadratic
Proventriculus											
6 d	154	126	95	68	110	22.4	11.2				
12 d	124	85	101	77	97	15.6	7.8				
18 d	126	102	93	68	97	13.6	6.8				
Average	134^{x}	104^{xy}	96^{y}	71^{y}		11.9		0.002	0.850	0.309	0.395
Gizzard											
6 d	170	374	374	369	322	16.1	8.1				
12 d	177	367	366	355	316	14.0	7.0				
18 d	178	377	362	349	317	21.1	10.5				
Average[d]	175^{y}	373^{x}	367^{x}	358^{x}		11.1		<0.001	<0.001	0.706	0.736
Ceca											
6 d	301	469	433	384	397^{Y}	25.6	12.8				
12 d	464	478	612	593	537^{X}	43.9	22.0				
18 d	406	615	528	540	522^{X}	35.6	17.8				
Average	390^{y}	521^{x}	525^{x}	505^{x}		19.2		0.001	0.001	<0.001	0.005
Gizzard digesta DM[e]	63.5^{y}	120.5^{x}	114.0^{x}	108.5^{x}		10.59		0.013	0.008		

[a] Standard error of mean for diet effect (n = 6 for each individual day and n = 18 for average age value).
[b] Standard error of mean for age effect (n = 24 observations for each age).
[c] The interactions between PH level and age for relative weight of the fresh digesta contents were not significant (P>0.10).
[d] Average of data at 6, 12 and 18 d of age.
[e] Data measured at 18 d of age.
[x,y] Means within a row not sharing a common superscript are different (P≤0.05).
[X,Y] Means within a column not sharing a common superscript are different (P≤0.05).

of the diet increased. The data of the current trial are consistent with the hypothesis that an increase in the pectins content of the chyme, as a consequence of increasing dietary PH, generates a physical dilation of the GIT with a concomitant increase in size of the digestive organs that in turn, favours gutfill (Jørgensen et al., 1996b; Jiménez-Moreno et al., 2009a). Hansen et al. (1992) in rats and Jørgensen et al. (1996a) in pigs have reported also a hypertrophy of gut tissues with high fibrous diets. Pectins and xylans, important constituents of the fibre fraction of PH, may be fermented partially in the ceca by the commensal microflora (Jørgensen et al., 1996b) resulting in an increase in the relative weight of the ceca as observed in the current experiment. The pH of the gizzard was reduced with the inclusion of 25 g PH/kg diet but no further changes were

Table 8
Effect of dietary pea hulls (PH) on digesta pH in different segments of the gastrointestinal tract of broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value[c]			
	0	25	50	75				PH		Age	
								Linear	Quadratic	Linear	Quadratic
Proventriculus pH											
6 d	4.53	3.93	4.06	4.07	4.15^{X}	0.095	0.047				
12 d	4.37	3.86	3.75	3.80	3.94^{Y}	0.149	0.074				
18 d	3.98	3.71	3.68	3.76	3.78^{Y}	0.166	0.083				
Average[d]	4.29^{x}	3.83^{y}	3.82^{y}	3.87^{y}		0.086		0.005	0.009	<0.001	0.797
Gizzard pH											
6 d	3.98	2.82	2.84	2.65	3.07^{X}	0.085	0.039				
12 d	3.80	2.50	2.56	2.51	2.84^{Y}	0.150	0.075				
18 d	3.51	2.38	2.48	2.46	2.71^{Y}	0.170	0.082				
Average	3.76^{x}	2.57^{y}	2.63^{y}	2.54^{y}		0.086		< 0.001	<0.001	<0.001	0.554
Duodenum pH											
6 d	6.22	6.28	6.23	6.27	6.25	0.050	0.025				
12 d	6.17	6.19	6.21	6.26	6.21	0.041	0.020				
18 d	6.08	5.96	6.19	6.20	6.11	0.158	0.079				
Average	6.16	6.14	6.21	6.25		0.063		0.266	0.704	0.100	0.439

[a] Standard error of mean for diet effect (n = 6 for each individual day and n = 18 for average age value).
[b] Standard error of mean for age effect (n = 24 observations for each age).
[c] The interaction between PH level and age for digesta pH of the segments of the gastrointestinal tract was not significant (P>0.10).
[d] Average of data at 6, 12 and 18 d of age.
[x,y] Means within a row not sharing a common superscript are different (P≤0.05).
[X,Y] Means within a column not sharing a common superscript are different (P≤0.05).

Table 9
Effect of dietary pea hulls (PH) on the relative length of the small intestinal and ceca (cm/kg of empty body weight) of broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value[c]			
	0	25	50	75				PH		Age	
								Linear	Quadratic	Linear	Quadratic
Small intestine[d]											
6 d	434	438	429	440	435[X]	8.0	4.0				
12 d	407	375	376	376	383[Y]	12.9	6.5				
18 d	125	131	127	124	125[Z]	5.6	2.8				
Average[e]	322	315	308	313		6.0		0.246	0.327	<0.001	<0.001
Ceca											
6 d	66.4	68.7	67.3	70.5	68.2[X]	1.80	0.90				
12 d	35.0	34.3	32.6	33.9	34.0[Y]	1.16	0.58				
18 d	24.3	25.5	25.1	25.4	25.1[Z]	1.10	0.55				
Average	41.9	42.8	41.7	43.3		0.85		0.439	0.718	<0.001	<0.001

[a] Standard error of mean for diet effect ($n = 6$ for each individual day and $n = 18$ for average age value).
[b] Standard error of mean for age effect ($n = 24$ observations for each age).
[c] The interaction between PH level and age for the relative length of the small intestinal and ceca was not significant (P>0.10).
[d] Small intestine = duodenum + jejunum + ileum.
[e] Average of data at 6, 12 and 18 d of age.
[X–Z]Means within a column not sharing a common superscript are different (P≤0.05).

Table 10
Effect of dietary pea hulls (PH) on jejunal morphology in broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value			
	0	25	50	75				PH		Age	PH × age
								Linear	Quadratic		
Villus height (μm)											
12 d	941	986	849	784	890	75.0	37.5				
18 d	786	875	855	719	808	75.0	37.5				
Average[c]	863	930	852	751		53.0		0.088	0.122	0.132	0.739
Crypt depth (μm)											
12 d	142	135	119	113	128	7.4	3.7				
18 d	108	98	111	107	106	7.4	3.7				
Average	125[x]	118[xy]	115[xy]	110[y]		5.2		0.046	0.837	<0.001	0.050
Villus height:crypt depth ratio											
12 d	6.98	7.69	7.39	7.27	7.45	0.552	0.276				
18 d	7.66	9.52	8.86	7.02	8.26	0.552	0.276				
Average	7.31[y]	8.83[x]	8.13[xy]	7.14[y]		0.390		0.489	0.003	0.043	0.388

[a] Standard error of mean for diet effect ($n = 6$ for each individual day and $n = 18$ for average age value).
[b] Standard error of mean for age effect ($n = 24$ observations for each age).
[c] Average of data at 12 and 18 d of age.
[x,y]Means within a row not sharing a common superscript are different (P≤0.05).

observed with further PH increases. The decrease in pH observed suggests that the fibre fraction of PH may stimulate bile salts and bicarbonate secretions (Sommer and Kasper, 1984; Hetland et al., 2003).

In the current trial, crypt depth was reduced with age but villus height was not affected, resulting in higher villus height:crypt depth ratio at 18 d than 12 d of age. Also, Murakami et al. (2007) and Chou et al. (2009) observed that the villus height:crypt depth ratio increased with age (21 vs. 14 d of age) in agreement with the findings of the current trial. However, the increase in villus height:crypt depth ratio in these two last trials resulted primarily from an increase in villus height. The results of the current trial, showing higher crypt depth at 12 d of age are consistent with the faster tissue turnover that might have occurred in response to the mild digestive problem observed in birds at this age. Inflammation processes resulting from the presence of pathogens, cause sloughing of the villus cells and a concomitant increase in crypt depth. Crypt is the part of the villus in which the division of the stem cells takes place, allowing for the replacement of the epithelial cells (Iji et al., 2001).

The villus height:crypt depth ratio was highest with dietary PH of 25 g/kg. A further increase to 75 g PH/kg impaired the ratio. Hedemann et al. (2006) observed that newly weaned pigs fed diets high fibre tended to have shorter crypts than those fed low fibre diets. However, they did not detect any effect of dietary fibre on villus height and villus height:crypt depth ratio. A high villus height:crypt depth ratio is indicative of better function and maturity of the intestinal mucosa (Hampson, 1986). Thus, the inclusion of PH may have contributed to the improvement in nutrient digestibility observed as compared to the control diet.

Table 11
Effect of dietary pea hulls (PH) on the coefficients of total tract apparent retention (CTTAR) and apparent metabolisable energy nitrogen corrected (AME_n, MJ/kg) of the diet, and of apparent ileal digestibility (CAID) of nutrients in broilers.

Item	PH (g/kg)				Age	S.E.M.[a]	S.E.M.[b]	P-value[c]			
	0	25	50	75				PH		Age	
								Linear	Quadratic	Linear	Quadratic
CTTAR											
Dry matter											
6 d	0.775	0.790	0.779	0.757	0.776^{XY}	0.0041	0.0021				
12 d	0.768	0.788	0.775	0.751	0.771^{Y}	0.0041	0.0020				
18 d	0.773	0.794	0.785	0.758	0.777^{X}	0.0037	0.0019				
Average[d]	0.772^{y}	0.791^{x}	0.780^{y}	0.755^{z}		0.0023		<0.001	<0.001	0.522	0.022
Organic matter											
6 d	0.819	0.831	0.818	0.794	0.816	0.0035	0.0017				
12 d	0.815	0.833	0.820	0.793	0.815	0.0042	0.0021				
18 d	0.819	0.838	0.826	0.799	0.821	0.0040	0.0020				
Average	0.817^{y}	0.834^{x}	0.821^{y}	0.796^{z}		0.0025		<0.001	<0.001	0.074	0.234
Nitrogen											
6 d	0.641	0.660	0.658	0.644	0.650	0.0114	0.0057				
12 d	0.608	0.674	0.684	0.647	0.653	0.0123	0.0061				
18 d	0.631	0.676	0.689	0.650	0.661	0.0077	0.0039				
Average	0.627^{y}	0.670^{x}	0.677^{x}	0.647^{y}		0.0070		0.047	<0.001	0.120	0.675
Soluble ash											
6 d	0.441	0.521	0.529	0.512	0.509^{X}	0.0187	0.0094				
12 d	0.381	0.448	0.448	0.428	0.426^{Z}	0.0172	0.0086				
18 d	0.398	0.479	0.495	0.454	0.456^{Y}	0.0089	0.0044				
Average	0.407^{z}	0.483^{xy}	0.491^{x}	0.465^{y}		0.0074		<0.001	<0.001	<0.001	<0.001
Ether extract											
6 d	0.912	0.924	0.922	0.911	0.917^{X}	0.0047	0.0023				
12 d	0.903	0.913	0.911	0.909	0.909^{Y}	0.0047	0.0023				
18 d	0.906	0.926	0.921	0.918	0.918^{X}	0.0039	0.0019				
Average	0.907^{y}	0.921^{x}	0.918^{x}	0.913^{xy}		0.0032		0.317	0.008	0.794	<0.001
AME_n											
6 d	13.45	13.47	13.32	13.08	13.33^{X}	0.054	0.027				
12 d	13.35	13.40	13.22	13.02	13.24^{Y}	0.055	0.027				
18 d	13.44	13.51	13.46	13.19	13.40^{X}	0.047	0.024				
Average	13.41^{x}	13.46^{x}	13.33^{x}	13.10^{y}		0.031		<0.001	<0.001	0.064	<0.001
CAID at 18 d of age											
Dry matter	0.714^{xy}	0.725^{x}	0.714^{xy}	0.685^{y}		0.0097		0.041	0.054		
Organic matter	0.751^{x}	0.764^{x}	0.749^{xy}	0.719^{y}		0.0102		0.031	0.051		
Nitrogen	0.759^{z}	0.821^{x}	0.793^{y}	0.762^{z}		0.0085		0.660	<0.001		
Starch	0.902	0.942	0.939	0.936		0.0183		0.059	0.067		

[a] Standard error of mean for diet effect ($n = 6$ for each individual day and $n = 18$ for average age value).
[b] Standard error of mean for age effect ($n = 24$ observations for each age).
[c] The interaction between PH level and age for the coefficients of total tract apparent retention of nutrients was not significant (P>0.10).
[d] Average of data at 6, 12 and 18 d of age.
x–z Means within a row not sharing a common superscript are different (P≤0.05).
X–Z Means within a column not sharing a common superscript are different (P≤0.05).

4.3. CTTAR and CAID of nutrients

The CTTAR of most nutrients were lower at 12 d than at 6 or 18 d of age. Probably, the mild enteritis that affected birds at 12 d of age was responsible for the lower retention of nutrients observed at this age. In general, the inclusion of moderate amounts of PH (25–50 g/kg) improved nutrient digestibility whereas the inclusion of higher levels (75 g/kg) resulted in similar digestibilities to those observed with the control diets. Rogel et al. (1987) reported an increase in the digestibility of starch of raw potato in 42 d-old broilers as the level of oat hulls in the diet increased from 0 to 120 g/kg. In contrast, Jørgensen et al. (1996b) observed a reduction in the CTTAR and CAID of nutrients in 37 d-old broilers when 375 g PH/kg were used. Probably, the high levels of PH used in this study were responsible for the negative effects reported. The content of acid detergent fibre, acid detergent lignin and soluble DF of PH was of 358, 10.5 and 51 g/kg, respectively; indicating that PH are rich in cellulose and contain significant amounts of pectins (Bach Knudsen, 1997). Consequently, pectins from PH might increase digesta viscosity and the thickness of the unstirred water layers of the mucosa, which in turn might interfere with the diffusion and absorption of nutrients (Johnson and Gee, 1981; Forman and Schneeman, 1980). The data of the current research indicate that the inclusion of moderate amounts of PH (25–50 g/kg) benefits the development of the GIT, including gizzard function and jejunal mucosal structure, resulting in improvements in nutrient retention. However, high levels of dietary fibre from PH (more than 50 g/kg) have detrimental effects on many of these traits. These observations are consistent with the finding of Leterme et al. (1996) who observed an increase of endogenous nitrogen losses in pigs with the inclusion of PH and Leterme et al. (1998) who reported that the inclusion of high levels of fibre isolates from peas increased mucus output resulting in an increase in the ileal flow of nitrogen. Also, Hallsworth and Coates (1962) and Green (1988) reported that high DF diets enhanced abrasion in the small intestine of birds increasing endogenous cell losses to the lumen. These results may explain, at least in part, the reduction of ileal apparent nitrogen digestibility observed in the current research when high levels of PH were included in the diet.

In the current research, TTAR of ether extract improved quadratically with increasing PH level in the diet probably because of an increase in bile salts secretion. Hetland et al. (2003) reported that the inclusion of 100 g oat hulls/kg increased the concentration of bile acids and alpha-amylase in the chyme of broilers. Pea hulls because of its high pectins content have a low lipid adsorption capacity and a high water holding capacity and binding capacity for minerals (Torre et al., 1991). Thus, moderate amounts of PH may increase bile salts secretion and improve emulsification and absorption of the fat. However, high levels of dietary PH (75 g/kg) results in an excess of pectins in the chyme that may trap bile acids and minerals and hinder fat and soluble ash digestibility as observed in the current experiment.

5. Conclusion

The inclusion of moderate amounts of pea hulls in the diet (25–50 g/kg) improves nutrient retention and growth performance of broilers. Therefore, young broilers have a requirement for dietary fibre. When pea hulls are used as a source of dietary fibre, the level of total dietary fibre required for optimal performance is within the range of 81.2–93.2 g/kg diet (25.6–35.0 g crude fibre/kg diet). However, higher levels of dietary fibre from pea hulls (75 g/kg diet equivalent to 105.1 g total dietary fibre/kg diet) reduce nutrient digestibility and growth performance to values similar to those observed with the control diet. Thus, under commercial conditions diets for young broilers should be formulated with a minimal and a maximal amount of dietary fibre.

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